TECHNICAL REPORT
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DEVELOPMENT OF HUMAN FACTORS ENGINEERING REQUIREMENTS FOR FIRE FIGHTING PROTECTIVE EQUIPMENT

by
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14. ABSTRACT
This report is the result of an effort to develop an understanding of fire fighters' needs through an assessment of relevent research and fire fighter-related literature, forums, conferences, and symposia. The objective was to understand what had and had not been accomplished regarding the development of fire fighter personal protection concepts and technologies. For the first time, the overall framework and system of studies and processes were reviewed at a strategic and policy level in addition to the tactical level. An attempt was made to look at the big picture of programs and studies instead of analyzing an isolated portion of the fire fighters' needs. This report examines many cirtical issues related to personal protective equipment in the post-Sept 11 fire service, and makes several astute recommendations.

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FIRES INTEGRATION FUTURE FORCE CRISIS MANAGEMENT STRUCTURAL PROPERTIES
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ENSEMBLE EMERGENCIES QUICK REACTION SOS (SYSTEM OF SYSTEMS) FFW (FUTURE FORCE WARRIOR)
MODULARITY FIRE FIGHTING FIRST RESPONDERS PROTECTIVE EQUIPMENT HUMAN FACTORS

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Dear Colleagues,

We are proud to announce the release of the ***Development of Human Factors Engineering Requirements for Fire Fighter's Protective Equipment – Final Report.*** This report is a cumulative effort from an expert panel with outstanding support from Ms. Rita Gonzalez, Director, National Protection Center, Natick Soldier Systems Center and Mr. John Hines, Technology Development Manager, Ames Research Center, National Aeronautics and Space Administration.

We would also like to thank U.S. Fire Administrator R. David Paulison, Federal Emergency Management Agency, and Vice Admiral Richard Carmona, United States Surgeon General, United States Public Health Service, for their contribution and support. Their interest, comments, and presentations at the opening of the panel were of great assistance.

The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of Defense, National Aeronautics and Space Administration, U.S. Fire Administration or U.S. Surgeon General position, policy or decision unless so designated by other documentation.

This report examines many critical issues related to personal protective equipment in the post-September 11 fire service, and makes several astute recommendations. We highly recommend that you read this excellent report

Sincerely,

Original Signed

Michael Hopmeier
President
Unconventional Concepts, Inc.

The Development of Human Factors Engineering Requirements for Fire Fighting Protective Equipment

Final Report

Michael Hopmeier
Chief, Innovative and Unconventional Concepts
Unconventional Concepts Inc.
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Support to the U.S. Army Natick Soldier Center
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PREFACE

This report was prepared by Unconventional Concepts, Inc., of Mary Esther, FL, under U.S. Army Natick contract number DADD16-03-C-0049 covering the period of October 2004 through August 2005. This report is the result of an effort to develop an understanding of fire fighters' needs through an assessment of relevant research and fire fighter-related literature, forums, conferences, and symposia. The objective was to understand what had and had not been accomplished regarding the development of fire fighter personal protection concepts and technologies. For the first time, the overall framework and system of studies and processes were reviewed at a strategic and policy level in addition to the tactical level. An attempt was made to look at the big picture of programs and studies instead of analyzing an isolated portion one the fire fighters' needs. This report examines many critical issues related to personal protective equipment in the post-September 11th fire service, and makes several astute recommendations.

EXECUTIVE SUMMARY

The *Development of Human Factors Engineering Requirements for Fire Fighting Protective Equipment* was a joint collaboration led by the U.S. Army Natick Soldier Center/National Protection Center (NSC/NPC) with the National Aeronautics and Space Administration (NASA) Ames Research Center and the Department of Homeland Security–U.S. Fire Administration (DHS-USFA). The purpose of the effort was to develop an understanding of fire fighter needs from an assessment of relevant research and fire fighter–related literature, forums, conferences, and symposia. The objective was to understand what had been done and what was accomplished regarding the development of fire fighter personal protection concepts and technologies. More important, what had *not* been done and deficiencies in the overall process were studied. This was not an effort to simply conduct another fire fighter requirements study and make recommendations. For the first time the overall framework and system of studies and processes were reviewed at a strategic and policy level in addition to the tactical level. An attempt was made to look at the big picture of programs and studies instead of analyzing an isolated portion of the fire fighters' needs.

This project identified gaps related to the definition of priorities, requirements, and deficiencies in technology roadmaps. The analysis provided a snapshot of the environment for the U.S. Army National Protection Center, the NASA Ames Research Center, the Department of Homeland Security Science and Technology Directorate, and the U.S. Fire Administration. It also provided guidance for other organizations and agencies that need an overview of the numerous current efforts in the field of fire fighter protection.

The project responded to the demand for improved personal protective clothing systems and the development of a comprehensive technology transfer program from government agencies to the fire service. The project methodology consisted of three key elements:

- a comprehensive literature search and analysis of threats related to protective equipment design, including findings from previous studies, with a unique matrix presentation of information that highlighted key deficiencies in the current study and investment process;
- an expert panel workshop to evaluate the literature search and the current state of fire fighter needs assessment with focus on process rather than actual solutions; and
- a final reporting of the literature analysis and summaries from the expert panel workshop.

Key findings of this effort included the following:

1. Although the vast majority of efforts to assist fire fighters focused on protection from fire environments, actual firefighting accounted for only 7% of their operations.
2. There are key deficiencies in the overall prioritization of study and analysis efforts as well as in coordination.
3. Although a large number of potential solutions to various fire fighting needs exist, their transition to the field is extremely poor.

4. Instead of developing new technology, there is a greater need to transition present technologies.
5. The culture and tradition of the fire service has been an impediment to protective equipment technology and physical fitness.
6. Violence is an escalating threat to fire fighters.

The primary conclusion of this project is that there is a serious need to establish a high-level organization, like the United States Fire Administration, to provide a structure for organizing the fractured and disparate efforts that presently exist in the fire fighter protective equipment field. Without a coordinated integration of research and technology, the fire fighter protection effort will continue its slow rate of progress.

DEVELOPMENT OF HUMAN FACTORS ENGINEERING REQUIREMENTS FOR FIRE FIGHTING PROTECTIVE EQUIPMENT

INTRODUCTION

Purpose

The protective equipment requirements of the American fire service have not been assessed in a coordinated and cohesive manner. The intent of the *Development of Human Factors Engineering Requirements for Fire Fighting Protective Equipment* panel was to determine the relevance of past studies and standards by comparing these efforts with present-day and emerging threats to identify overall process gaps.

This project will assist the Natick Soldier Center, the NASA Ames Research Center, and other interested federal government agencies in defining roles and areas of interest within the homeland security paradigm, program planning, technology transfer, doctrine development, and program implementation. The final objective of this project was to summarize findings from an expert panel and recommend specific actions for future efforts to develop fire fighter protective equipment.

Background

Many federal government agencies, such as the Department of Defense (DOD) and the NASA Ames Research Center, have comprehensive technology transfer programs. They are under continuous public and political pressure to identify high pay-off transferable technologies that address technology gaps in homeland security operations, such as personal protective clothing in the environment after the attacks of September 11, 2001. The primary method for implementing this mission is through a study process. This process has been performed multiple times in the last twenty years. Unfortunately, the vast numbers of studies were disjointed, consisting of narrowly focused non-systemic efforts. The overall process had no strategic or policy coordination; these uncoordinated efforts continue.

Technology transfer programs within the NASA Ames Research Center and the Department of Defense have initiated technology transfer efforts for improved personal protective equipment since the 1970s. The NASA National Technology Transfer Center is a source of research for advances in nanotechnology and human performance in extreme environments. Fire fighter turnout gear dating to the early 1900s was updated in the 1970s through Project FIRES. Project FIRES was initiated in 1976, with funding provided by the U.S. Fire Administration and other sources, to adopt state-of-the-art technology in the textiles and materials sciences to improve fire fighter protection. The success of Project FIRES resulted in the establishment of the Congressional Fire Services Institute.

> Whether you are a fire fighter, emergency services responder, manufacturer or fire service leader, the United States Congress is more aware of your concerns because of the Congressional Fire Services Institute (CFSI). Established in 1989 as a nonprofit, nonpartisan policy institute, CFSI is designed to educate members of Congress about the needs and challenges of our nation's fire and emergency services so that the federal government provides the types of training and funding needed by our first responders.
>
> ~www.cfsi.org

The need for protecting fire fighters from a myriad of threats has increased throughout fire service history. Originally, fire service protective equipment consisted of a rubber coat and a leather helmet. Respiratory protection was developed in the 20th century. Current fire fighter turnout gear was assessed by Project FIRES with 1970s technology as a benchmark. The bombing of the Oklahoma City Murrah Federal Building in 1995, the subsequent Nunn-Lugar-Domenici bill of 1998, and the realities of September 11, 2001, expanded these requirements within the framework provided by Homeland Security Presidential Directives HSPD-5, Management of Domestic Incidents, and HSPD-8, National Preparedness. There was a higher focus on multi agency collaboration in high-risk terrorism operations. The presidential directives and policies placed greater attention on chemical, biological, radiological, nuclear, and explosive (CBRNE) hazards. These threats complicate daily operational challenges including toxic chemicals from the operational environment.

The baseline literature analysis revealed that a significant amount of federal funds was allocated to upgrade fire fighter protection. There were indications that the fire community has perhaps received more attention and funding than acknowledged by associations, industry, and other interested participants. Correlating the fire fighter literature with other professional studies revealed more emphasis on fire fighter protection than on other emergency response issues

Examples of past major studies include:

- The National Institute for Occupational Safety and Health (NIOSH) commissioned the RAND Corporation and other entities to prepare studies to identify technology gaps and concerns with focus on respiratory equipment and emerging occupational hazards in the fire service. Their main focus was on the fire service. The NIOSH established its National Personal Protective Technology Laboratory (NPPTL) to provide further research on respiratory protection and to assess the integration of respiratory protection and other equipment. The NPPTL is responsible for consolidating the NIOSH personal protective equipment (PPE) standards mission. The NPPTL is also exploring concepts related to advanced fire fighter protection gear, deriving many of their concepts from military, academic, and government-based programs.

- The Memorial Institute for the Prevention of Terrorism (MIPT) spearheaded Project RESPONDERS to establish a baseline for emergency responder requirements. Project RESPONDERS introduced the concept of technology readiness levels, deriving taxonomy from both NASA Ames Research Center and DOD research efforts. The MIPT has also hosted nationwide focus groups for emergency responders and developed the Responder Knowledge Base, an informative database that publicizes a wide range of literature related to emergency response. A significant percentage of the MIPT literature is dedicated to the personal protective needs of fire fighters.

The dangers faced by fire fighters today have increased in number and type, and include those innate to terrorism response. There are many parallel efforts that have not been effectively coordinated by the U.S. Fire Administration. Technology transfer programs, federal funding, and interagency cooperation exist, but they focus more on personal protective equipment than on other emergency response environments that fire fighters are increasingly forced to deal with.

STUDY PROCESS

Overview

The Natick Soldier Systems Center and the NASA Ames Research Center teamed with the U. S. Fire Administration to analyze and assess related literature, including research efforts and information. The process followed a three-step methodology:

- a baseline literature collection and analysis by the DHS National Emergency Training Center's (NETC) Learning Resource Center and Unconventional Concepts Inc. (UCI);
- an expert panel workshop; and
- a final reporting of the literature analysis with panel findings.

The Learning Resource Center conducted a baseline literature search that was consolidated and analyzed by Mr. Hank Christen, Director of Emergency Response Operations for UCI and members of an expert panel prior to the workshop. The panel conducted initial discussions with conference calls. The panel was convened in Arlington, Virginia, on September 1–2, 2004. Mr. David Paulison, U.S. Fire Administrator; Vice Admiral Richard Carmona, U.S. Surgeon General; Dr. Phil Brandler, Director, Natick Soldier Center; Dr. David Boyd, Director, Office for Interoperability and Compatibility, Science and Technology Directorate, DHS; and senior management from the DHS and other agencies attended the workshop. Panel observers included key members from the Memorial Institute for the Prevention of Terrorism and the DHS Science and Technology Directorate, including the Office of Interoperability and Compatibility and the Office of Domestic Preparedness.

Panel Process

The panel selection was based on technical expertise and professional experience. The panelists represented a cross section of the fire service, law enforcement, emergency medical services, and industrial sector. Panel members were given an extensive notebook prior to the panel workshop. The notebook included a project description, an overview of relevant standards, studies, articles, and a comprehensive bibliography of protective equipment literature. The studies and standards were graphically summarized in a matrix.

The panel members participated in two conference call sessions prior to the scheduled meeting. The first conference call was a pre-workshop briefing to explain the purpose of the project. The second conference call was a discussion of the literature search and studies and standards analysis using the notebook matrices as a discussion template. The panel was instructed to concentrate on critical questions in the workshop such as:

1. What are the deficiencies in the present standards and studies?
2. What are the subsystems and their interfaces in fire fighting operations?
3. What system interface requirements are needed that are not presently addressed?
4. How does the fire fighter culture relate to protective equipment design?
5. What are the recent lessons learned that are not included in the literature?
6. How does the changing fire fighter's mission relate to protective equipment requirements?

The panel moderator was Hank Christen. He was assisted by Michael Malone, Director of Military and Civilian Integration for UCI, and Mr. Al Sciarretta, CNS Technology. The other participants were:

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The panel began the workshop by discussing the culture of the fire service. Panel members expressed deep concern regarding the fire fighters' culture and its role as an impediment to protective equipment development. This mindset is driven by strong alliances that are persuasive enough to influence many decision processes. Panel members expressed, "The *culture* is the enemy; two hundred years of tradition unimpeded by progress is often the fire service template." The attributes of the culture that impede effective protective equipment systems were identified. Panel members agreed that cultural issues must be overcome by standards that are strictly enforced

by senior management, with accountability and trust between managers, fire fighters, fire representative groups, and government. Management accountability is a key aspect of any viable solution.

The panel took a system-of-systems approach by considering the protective ensemble as a subsystem. The members identified other subsystems, critical linkages, and their relationship to the operations system. It was noted that no studies have been conducted based on a system-of-systems concept.

The panel confined the scope of this effort to the structural fire service in the United States. Specialized fire suppression operations such as wildland fire fighting, oil well fire fighting, and aviation or marine fire fighting were not within the charge of the panel. The panel did include non–fire fighting operations such as (but not limited to) medical response, urban search and rescue, technical rescue, auto extrication, law enforcement support, and hazardous materials operations.

The panel addressed the effects of fire fighter personal fitness on equipment systems and subsystems. However, fitness requirements and the imposition of fitness on the culture were not within the panel's scope.

The panel examined baseline tasks, conditions, and standards relating to fire fighter protective equipment and discussed current strategic issues revealed in the literature such as the following:

1. Despite the many parallel efforts, there are still no clear definitions of the environmental threat, defined doctrine, concepts of operation, spiral technology development, and technology insertion points.
2. There is no effective analysis of existing technologies relating to defined threats, nor is there a process to assess the viability of the technologies.
3. Endeavors have evolved as parallel projects instead of cohesive efforts; most endeavors have not been coordinated with the U.S. Fire Administration or the relevant lead federal agencies.
4. There were fiscal expenditures for repetitious studies and findings that did not identify *core* problems of fire fighter protection.

RESULTS

Analysis of Matrix Results

One of the key tasks required of UCI was an overall assessment of the current state of analysis and studies within the field of fire fighter technology needs. An initial review identified more than twenty studies that were done by organizations in the last thirty years using various methods. Given the number and diversity of these reports, some method was needed to effectively present and analyze this mountain of data and reports. After internal discussions, UCI developed a unique matrix process for analyzing the literature search findings. The National Fire Protection Association (NFPA) Standards Matrix contains fifteen standards and is represented on page 12. The Studies Matrix contains 23 protective equipment studies (page 13). In both matrices 33 key categories were analyzed. These methods consisted of the following steps to consolidate the information, present it, and analyze it:

1. Collection of available information
2. Creation of key parameters to apply to each report or study
3. Population and creation of the matrix
4. Analysis

If a key category was addressed in a standard or study, the appropriate matrix box was marked with an "X." No attempt was made at assigning a numerical value to a matrix selection. The following points are a summary of the deficiencies revealed in the Studies Matrix and Standards Matrix:

1. **Ballistic protection**—No standards or studies reflected the threat or the need for protection from violence even though it is an increasing hazard to fire fighters, especially on medical responses.
2. **Body cooling**—Only two standards referenced body cooling, whereas seven studies identified body cooling as a requirement.
3. **Cost**—No standards referenced cost. However, cost was addressed in seven studies.
4. **Cultural issues**—Tradition and culture remain major impediments to the design of protective equipment. No studies or standards adequately addressed this prevailing issue.
5. **Level changes**—No standards or studies established requirements for changing personal protection levels as hazards or threats changed.
6. **Explosive protection**—Presently, standards do not address protection from explosive hazards; five studies discuss explosive hazards.
7. **Fitness**—Standards appear to assume that all users are appropriately physically fit; several studies identified improper levels of fitness as a major contributor to deaths and injuries.
8. **Monitoring**—Present standards and studies have not recognized the advantages of physiological monitoring and modern sensor technology.
9. **Size issues**—Gender sizing and equipment ergonomics for female users have not been adequately considered.
10. **System to system**—The standards address individual components without considering interface issues with other systems.
11. **Threats**—The standards do not consider emerging nontraditional threats.

12. **Vehicle interface**—The standards and studies did not address restraint systems, body protection, and head protection from vehicle accidents. This is a significant deficiency considering that vehicle accidents account for 25% of fire fighter fatalities.
13. **Weight issues**—The weight reduction of protective equipment is examined in several studies but not considered adequately in the standards.

Table 1 (page 8) is a summary of deficiencies based on the matrix assessment. In some cases a study or a standard failed to address a category. In other cases both the studies and the standards failed to address a given key category. The key deficiencies *common* to both the studies and the National Fire Protection Association standards were

1. ballistic protection,
2. cultural user issues,
3. changes of protection levels,
4. sensor capabilities,
5. vehicle interface with users, and
6. violence and assault protection.

The findings of the matrix process were reviewed and discussed by the expert panel prior to the Arlington workshop. The gaps analysis of the standards and the studies served as a template that guided the ensuing panel discussions.

Table 1. A Comparison of Standards and Studies Deficiencies

Standards Deficiencies	Studies Deficiencies
Ballistic protection	Ballistic protection
Body cooling	
Cost issues	
Cultural user issues	Cultural user issues
Explosive protection	
Fitness	
Incident command system	
Level (changes of protection levels)	Level (changes of protection levels)
Monitoring (physiological)	
Power requirements	
Radiation protection	
Rehabilitation requirements	
Sensor capabilities	Sensor capabilities
Stress (physical and mental)	
System-to-system relationships	
Size issues (gender)	
Threats (nontraditional)	
Threshold limits for components	
Vehicle interface with users	Vehicle interface with users
Violence and assault protection	Violence and assault protection
Weight of components	

Table 2. Matrix of Literature Search Findings Relating to Fire Fighter Standards

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI
1	**Standards**	Ballistic	Biological	Chemical	Cooling	Cost	Culture	Decon	Dexterity	Doctrine	Explosive	Fitness	ICS	Interface	Level Chg.	Maintenance	Monitoring	Power req.	Radiation	Rehab	Respiratory	Sensors	Spec Ops	Stress	Service life	Sys to Sys	Size	Thermal	Threats	Thresholds	Training	Vehicles	Violence	Weight		
2	1404 Res Trng									x				x		x					x										x				
3	1500 Safety									x			x	x						x	x		x	x							x	x	x		
4	1521 Safe Ofc		x	x				x		x		x	x	x						x			x	x							x	x			
5	1582 Occ Med		x						x	x		x					x														x				
6	1583 Fitness						x		x	x		x					x														x				
7	1851 PPE maint		x	x				x		x						x									x			x							
8	1852 SCBA care							x		x																					x				
9	1951 USAR				x				x	x				x		x							x				x								
10	1971 Fire PPE				x			x	x	x				x		x										x	x			x				
11	1975 Uniform									x				x														x							
12	1981 SCBA			x						x				x		x		x			x				x			x			x				
13	1982 PASS			x						x				x		x		x										x			x				
14	1991 Vapor prot		x	x				x	x	x				x											x			x	x						
15	1994 CBW PPE		x	x				x	x	x				x											x			x							
16	1999 EMS PPE		x							x				x																					
17																																			
18	Totals	0	6	6	2	0	1	6	6	15	0	3	2	11	0	6	2	2	0	2	3	0	3	2	4	0	1	7	2	0	9	2	1	0	

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Table 3. Matrix of Literature Search Findings Relating to Fire Fighter Studies

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI
1	**Studies**	Ballistic	Biological	Chemical	Cooling	Cost	Culture	Decon	Dexterity	Doctrine	Explosive	Fitness	ICS	Interface	Level Chg.	Maintenance	Monitoring	Power req.	Radiation	Rehab	Respiratory	Sensors	Spec Ops	Stress	Service life	Sys to Sys	Size	Thermal	Threats	Thresholds	Training	Vehicles	Violence	Weight		
2	Pro Emer Resp		x	x				x	x	x			x	x			x	x		x	x			x		x	x		x		x			x	
3	NIOSH RAND 2		x	x	x	x		x	x	x			x	x				x	x		x	x					x	x			x			x	
4	Proj Responder		x	x	x	x		x	x	x	x		x	x			x	x			x	x		x					x					x	
5	IAB Strategy							x		x											x								x						
6	Fatality RAND											x									x		x	x					x			x			
7	Next Gen PPE		x	x	x	x								x							x				x			x		x					
8	Tampa summit					x	x						x								x								x		x	x			
9	IAB Rep 2002		x	x	x	x		x	x		x			x		x	x		x		x		x			x		x	x	x				x	
10	JSLIST Army		x	x				x	x					x		x					x				x										x	
11	Pro HEROES		x	x	x				x					x					x		x		x	x				x	x	x					
12	Heat Trans Mod				x																			x				x		x					
13	Redmond		x	x	x							x							x		x			x				x	x						
14	IAB Rep 2003		x	x	x	x		x	x	x	x			x		x	x		x		x		x			x		x		x				x	
15	CDC APR		x	x						x		x			x	x					x				x		x		x	x	x				
16	NW F Fighters											x									x								x						
17	Pro Res NIOSH		x	x				x				x	x	x			x			x						x		x	x		x				
18	NIOSH DOD Res		x	x		x		x		x				x			x				x		x		x				x	x	x				
19	BA Failures															x	x				x	x			x		x			x	x			x	
20	CBR Suits FEMA		x	x	x				x					x			x							x											
21	Decon Aid NIST		x	x				x		x	x		x						x	x	x		x					x							
22	Eval ASTM 1154			x					x												x						x								
23	CW Res Guide		x	x				x		x	x		x				x				x					x									
24	1st Resp Mask		x	x						x								x		x	x			x			x		x	x					
25																																			
26	Totals	0	16	17	9	7	1	11	9	10	5	5	7	13	1	5	9	4	6	4	20	3	6	8	5	5	6	8	14	9	7	2	0	7	

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The following is a list of the nomenclature used in the above matrix:

B **Ballistic**—protection from firearms
C **Biological**—biological protection or issues
D **Chemical**—chemical protection or issues
E **Cooling**—body cooling
F **Cost**—cost issues
G **Culture**—cultural user issues
H **Decon**—decontamination
I **Dexterity**—dexterity and flexibility
J **Doctrine**—doctrine or procedures
K **Explosive**—protection from explosives
L **Fitness**—user physical fitness
M **ICS**—incident command system
N **Interface**—compatibility of PPE components
O **Level chg**—change of protection levels as threats change
P **Maintenance**—maintenance of components
Q **Monitoring**—physiological monitoring of users
R **Power req.**—electrical power requirements
S **Radiation**—radiological threats
T **Rehab**—rehabilitation
U **Respiratory**—respiration hazards or issues
V **Sensors**—sensor capability
W **Spec ops**—special operations issues
X **Stress**—physical or mental user stress
Y **Service life**—useful life of a component
Z **Sys to Sys**—relationship of one system to another system
AA **Size**—PPE sizing issues
AB **Thermal**—heat degradation of materials
AC **Threats**—nontraditional threats or hazards
AD **Thresholds**—limits for PPE components
AE **Training**—training requirements
AF **Vehicles**—vehicle interface with users
AG **Violence**— physical attacks against responders
AH **Weight**—component or equipment weight issues

The following is a list of the standards referenced in Table 2:

1404 Standard for Fire Service Respiratory Protection Training, 2002 Edition
1500 Standard on Fire Department Occupational Safety and Health Program, 2002 Edition
1521 Standard for Fire Department Safety Officer, 2002 Edition
1582 Standard on Comprehensive Occupational Medical Program for Fire Departments, 2003 Edition
1583 Standard on Health-Related Fitness Programs for Fire Fighters, 2000 Edition
1851 Standard on Selection, Care, and Maintenance of Structural Fire Fighting Protective Ensembles, 2001 Edition
1852 Standard on Selection Care, and Maintenance of Open-Circuit Self-Contained Breathing Apparatus (SCBA), 2002 Edition
1951 Standard on Protective Ensemble for USAR Operations, 2001 Edition
1971 Standard on Protective Ensemble for Structural Fire Fighting, 2002 Edition
1975 Standard on Station/Work Uniforms for Fire and Emergency Services, 2004 Edition
1981 Standard on Open-Circuit Self-Contained Breathing Apparatus for Fire and Emergency Services, 2002 Edition
1982 Standard on Personal Alert Safety Systems (PASS), 1998 Edition
1991 Standard on Vapor-Protective Ensembles for Hazardous Materials Emergencies, 2000 Edition
1994 Standard on Protective Ensemble for Chemical/Biological Terrorism Incidents, 2001 Edition
1999 Standard on Protective Clothing for Emergency Medical Operations, 2003 Edition

The following is a list of the studies referenced in Table 3:

Pro Emer Resp—Protecting Emergency Responders, Lessons Learned from Terrorist Attacks
NIOSH RAND 2—Protecting Emergency Responders, Volume 2, Community View of Safety and Health Risks and Personal Protection Needs; RAND/NIOSH
Proj Responder—Project RESPONDER
IAB Strategy—Interagency Board for Equipment Standardization and Interoperability Strategic Plan for Developing a Suite of Chemical, Biological, Radiological, Nuclear, and Explosives Protective Equipment Standards
Fatality RAND—Emergency Responder Injuries and Fatalities: An Analysis of Surveillance Data; RAND Science and Technology
Next Gen PPE—Next Generation Structural Fire Fighting PPE with Chemical/Biological Protection; technical proposal
Tampa Summit—Firefighter Life Safety Summit Initial Report (Tampa Summit), Federal Emergency Management Agency (FEMA), April 2004
IAB Rep 2002—Interagency Board for Equipment Standardization and Interoperability, 2002 Annual Report
JSLIST Army—Joint Services Lightweight Integrated-Suit Technology (JSLIST); U.S. Army
Pro HEROES—Project Heroes: Homeland Emergency Response Operational and Equipment Systems

Heat Trans Mod—A Heat Transfer Model for Fire Fighter's Protective Clothing (NISTIR 6299); National Institute of Standards and Technology
Redmond—17th Symposium on the Occupational Health and Hazards of the Fire Service; Redmond Foundation Symposium
IAB Rep 2003—The Interagency Board, 2003 Annual Report
CDC APR—Summary Report of the Working Group to Review Distribution of Personal Respiratory Protective Equipment to the General Public at Chemical Stockpile Sites
NW F Fighters—Northwest Fire Fighters Mortality Study: 1945–1989; FEMA, U.S. Fire Administration
Pro Res NIOSH—Protecting Emergency Responders, Volume 3, Safety Management in Disaster and Terrorism Response; NIOSH
NIOSH DOD Res—NIOSH-DOD-OSHA Sponsored Chemical and Biological Respiratory Protection Workshop Report; U.S. Department of Health and Human Services
BA Failures—Prevention of Self-Contained Breathing Apparatus Failures; U.S. Fire Administration
CBR Suits FEMA—Field Evaluation of Chemical Protective Suits; FEMA
Decon Aid NIST—Aid for Decontamination of Fire and Rescue Service Protective Clothing and Equipment after Chemical, Biological, and Radiological Exposures; NIST
Eval ASTM 1154—Evaluation of ASTM Standard F-1154, Qualitatively Evaluating the Comfort, Fit, Function and Integrity of Chemical Protective Suit Ensembles
CW Res Guide—Guidelines for Responding to a Chemical Weapons Incident, Domestic Preparedness Program
1st Resp Mask—Physiological Evaluation of First Responder Mask; Army Research Laboratory

OVERVIEW OF RESULTS

Doctrine

The following is an overview of the results of the panel discussions regarding fire fighter doctrine.

1. Firefighter fitness is important and requires emphasis. Stress is the number one killer of fire fighters, yet most fire fighters do not meet minimal physical fitness standards. The panel noted that comparisons with military equipment requirements are not relevant because military personnel far exceed the physical fitness levels of most fire fighters.

2. Violence and assaults are not recorded; only actual injuries are reported. More data are needed relating to violence threats. There is a need for a national violence reporting system similar to the Uniform Fire Incident Reporting System (UFIRS).

3. The importance of the fire service integrating with emergency medical service (EMS) and law enforcement in using the incident command system was emphasized. Non command activities could be combined in various cities between law enforcement, EMS, and fire services. For example, physical fitness programs, face-piece testing, and certain aspects of training should be interagency functions.

4. The aviation industry's concept of crew resource management should be adopted by the fire service. Aviation studies reveal that accidents are usually caused by human error instead of equipment failure. In an aircraft cockpit, it is the duty of subordinates to challenge and confirm orders that appear to be unclear or unsafe during flight operations. This is also called "obedient disobedience." The fire service should apply this doctrine to tactical operations.

5. The aviation industry has also implemented the concept of reporting and analyzing near misses The fire service needs to develop a similar near-miss reporting system (sometimes called a "near-hit system"). Near misses greatly outnumber actual accidents and are a predictor of future accidents.

6. There were discussions on the Los Angeles riots, the Worcester fire, and the Pentagon attack. The main points were the effectiveness of the Incident Command System as a model for interoperability between diverse agencies, the ineffectiveness of standard turnout gear in long-term operations, and the need for an on-scene personnel accountability system.

7. Equipment compatibility is critical; however, most protective equipment components are not interchangeable. Compatibility can also fluctuate as regional agencies upgrade their equipment without interagency coordination.

Technology

The following is an overview of the results of the panel discussions regarding fire fighter technology.

1. It is assumed that a fire fighter's most common activity is fire fighting. However, a fire fighter's daily response activity in 2003 was 7% fire calls and 60% medical incidents (the percentage of medical calls in some urban areas exceeded 75%). Other calls included hazardous materials incidents and technical rescue operations (NFPA 2005a). In spite of the response figures, many studies still focus on protection from heat and other fire fighting hazards. Suitable alternatives to heavy and bulky turnout clothing must be developed for daily response activities such as medical and technical rescue operations.

2. The work uniform is only a costume that displays a patch and a nametag. There is a need to develop a minimal level of day-to-day protection using the work uniform as the core garment. The objective is to use a protective work uniform when turnout gear is not needed. An NFPA work uniform standard for police, fire, and EMS is needed because their missions seem to be similar, especially in medical responses.

3. There is a need for improved biological protection. Fire fighters rarely encounter biological terrorism, but they are continually exposed to biological pathogens during medical responses. The main concerns are body fluid contact at medical scenes or violence incidents that result in exposure to hepatitis, tuberculosis, AIDS, and other infectious diseases.

4. Vehicle crashes are the second major cause of fire fighter fatalities, but the fire service has not adopted crash protection technology from other disciplines. These technologies include head protection and harness restraint systems that have been applied by the aviation and auto racing industries and are not addressed by the fire service.

5. Interoperability of equipment, procedures, and scene coordination is important between fire, EMS, and law enforcement agencies because their missions overlap. Fire and EMS units are responding to violence calls and law enforcement units are responding to medical calls with equipment such as AEDs (automatic electronic defibrillators).

6. Violent attacks on fire fighters and other responders are increasing; violence is a rural, suburban, and urban problem. As a result, ballistic garments are needed for fire fighters that include protection against blunt trauma and knife attacks.

7. A key question is, "What are the negative aspects to a fire fighter's health regarding continuous exposure on a day-to-day basis to body fluids, stress, and products of combustion?" The effects of long-term exposure to biological pathogens, physical and mental stress, and products of combustion must receive further study. Thresholds must

be identified, with a daily reduction of exposure as a goal. There must also be a capability to determine real-time thresholds so that personal protective equipment levels can be changed during emergency operations.

Culture

The following is an overview of the results of the panel discussions regarding fire fighter culture.

1. The fire fighter culture is a major impediment to protective equipment design. In many cases equipment design is guided mainly by what a fire fighter's gear is supposed to look like. Many American fire departments are still wearing traditional helmets instead of the modern Gallet helmet worn by European fire fighters. The Gallet helmet is superior, especially when considering crash protection and the mask interface, but it does not fit the American fire fighting culture.

2. Fire service managers must be held accountable for developing and enforcing compliance with safety and physical fitness standards and exerting proactive leadership to eliminate the negative aspects of the fire service culture. The panel unanimously advocated a system of national-level credentialing and recertification for mid-level and senior executives to ensure effective management and accountability.

CONCLUSIONS AND RECOMMENDATIONS

The expert panel developed specific recommendations after a detailed analysis and extended discussions. The following conclusions and recommendations are the findings of the panel.

1. The fire fighter culture inhibits protective equipment innovations.

How equipment looks often dictates protective equipment decisions; if it does not look right, fire service managers will not buy it. An example is the 19th-century leather helmet that provides very poor vehicle crash and assault protection and provides an inadequate helmet-to-mask interface. The panel placed serious emphasis on management and accountability to counter the negative effects of the prevailing fire fighter culture. The culture in the fire service must not override sensible requirements. There is a need for operationally defined requirements instead of perceived parochial ones. Managers must advocate better standards and overcome tradition instead of being part of the cultural problem.

1-1 Recommendation—Fire service executives should implement and enforce effective standards instead of allowing tradition to be the template for determining what protective equipment to implement.

1-2 Recommendation—Develop a new standard for fire fighter protective headgear that establishes requirements for an effective helmet-to-mask interface that includes protection from vehicle crash and assault injuries.

1-3 Recommendation—Develop a national requirement for credentialing and recertifying fire service officers and executives that is enforced to ensure management accountability.

2. What a firefighter does on a normal day has significance.

This consideration has not been previously highlighted in the literature. Fire fighters wear turnout gear on every call, meaning that they are properly dressed only 7% of the time. More than 60% of fire responses are for auto accidents, trauma injuries, and medical emergencies such as cardiac events, diabetic emergencies, and sickness. Other calls are for hazardous materials, technical rescue, and miscellaneous services. Although terrorism captures the headlines, few American fire fighters will ever respond to a terrorism incident.

2-1 Recommendation—Studies and standards should focus on the all-hazard environment instead of just fire fighting operations.

2-2 Recommendation—Develop a standard of protection for the fire department work uniform that is also applicable to law enforcement and EMS users; adopt the work uniform as a core protective garment.

2-3 Recommendation—Develop a biological protection standard for all components of the protective ensemble, with a focus on body-fluid isolation.

3. Violence is a common threat that is often overlooked.

Dr. Don Walsh's study, *An Analysis of Paramedic Occupational Violence* (1996) shows that the level of violence encountered by emergency responders is increasing. Violence is almost at the same level in rural areas as in urban areas such as Chicago. Violent threats to fire fighters are biological, traumatic, and ballistic. Fire fighters need ballistic protection and shielding from blunt trauma and knife attacks.

3-1 Recommendation—Develop a study to identify the injuries sustained by fire fighters from violence or assaults similar to studies related to fire fighting injuries.

3-2 Recommendation—Develop a standard for ensemble components that provide ballistic shielding, knife protection, and blunt force trauma protection.

4. Stress and exertion is the number one killer of fire fighters.

The studies, findings, and literature on fitness are prolific, yet they are often ignored. The result is a level of physical fitness in the American fire service that is substandard and may explain why 50% of fire fighter deaths are related to cardiac events and overexertion. Many fire fighters are overweight smokers with high blood pressure; this may relate to their culture and the fact that management is not implementing physical fitness standards. This factor also inhibits the transition of military technology to the fire service because military equipment is designed for a healthy young soldier—a population that is not comparable to American fire fighters.

4-1 Recommendation—Conduct a research study to identify why physical fitness programs are poorly implemented and enforced in the American fire service.

4-2 Recommendation—Conduct a research study to identify and quantify the causes and effects of mental stress relating to fire fighters.

4-3 Recommendation—Develop requirements for body cooling and weight reduction in protection systems to reduce physical stress during emergency operations.

4-4 Recommendation—Develop a standard for protective garments required for long-term operations where turnout gear is neither suitable nor required.

5. The fire service must learn from other disciplines.

The fire service must examine other industries and disciplines to solve protective equipment problems. Vehicle accidents are an example. They are the number two cause of death to fire fighters, accounting for 25% of fire fighter fatalities. Clearly, vehicle crash protection must be reengineered and improved by applying lessons learned in the auto racing and aviation industries. In essence, the protection afforded to jet pilots and race car drivers should be applied to fire fighters.

5-1 Recommendation—Study auto racing and aviation restraint systems and incorporate the findings into fire service vehicle standards.

5-2 Recommendation—Upgrade head protection standards to require compatibility with facemasks and provide vehicle crash protection (forward, side, and rear protection from head trauma).

5-3 Recommendation—Incorporate the sizing and gender ergonomic design requirements used by the garment industry into fire service clothing and ensemble standards.

6. The fire service should adopt the principles of crew resource management.

The aviation concept of crew resource management is based on the premise that 80% of accidents are human related; poor communicating between crew members is often a contributing factor. This issue also applies to the fire service. Two key crew resource management procedures that enhance communications are called *obedient disobedience* and *challenge and confirm.* These principles mean that subordinates are obligated to question managers about unclear or unsafe decisions.

6-1 Recommendation—The fire service should adopt the doctrines of *challenge and confirm* and *obedient disobedience* as part of its leadership and tactical principles and doctrine.

6-2 Recommendation—The fire service should adopt a near-miss reporting system similar to the aviation industry and use the near-miss data as an accident-prevention and threat-analysis tool.

7. A system of tactical accountability must be developed.

Command officers must track and account for responders during emergency operations. This was a major problem in the Worcester fire. Tracking fire fighters, police, and EMS personnel in structures is important because the responsibilities of all three agencies are merging in many responses. Fire fighters must have the ability to find escape routes when they are trapped in a low-visibility environment. The tracking problem is similar to the military's problem of tracking soldiers in urban combat.

7-1 Recommendation—The fire service should sponsor a military and private sector collaboration effort to develop technology for tracking fire fighters and other emergency responders in low-visibility environments.

7-2 Recommendation—The fire service should utilize the National Incident Management System to develop requirements and integrate technology to maintain a common operational picture for all emergency response agencies during tactical operations

8. Occupational studies relating to long-term effects should be conducted.

Studies have not examined in detail the long-term effects from daily exposure after a 20- to 30-year career in fire fighting. Are fire fighters dying sooner after retirement than the general population? If so, why? More studies are needed to determine long-term exposure thresholds. There is also a need for a system of sensors and surveillance to determine needed equipment levels in real time.

8-1 Recommendation—The fire service should integrate sensor and monitoring technology into protective equipment ensembles to determine exposure thresholds in real time.

8-2 Recommendation—The fire service should conduct an in-depth study on the long-term effects of stress, products of combustion, and biological exposure on fire fighter morbidity and longevity.

9. Tactical interoperability issues should be addressed.

Critical equipment in emergency operations is often incompatible with other similar equipment. The most common examples are breathing equipment and communications devices. For example, multiple fire departments on large operations may have several different makes and models of breathing equipment with cylinders and regulators that are not interchangeable. The compatibility problems are even greater when law enforcement and EMS agencies are inserted into an operational environment. The underwater diving industry is an example of an excellent interoperability model. A standard scuba tank is compatible with commercial regulators and can be refilled in most areas of the world without special adaptors.

9-1 Recommendation—The fire service should initiate a study to develop compatibility and interoperability standards for critical components of fire fighting, EMS, and law enforcement protective equipment.

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